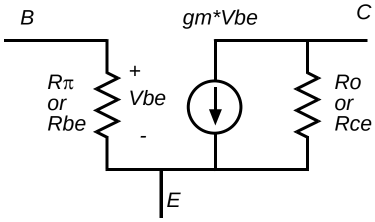
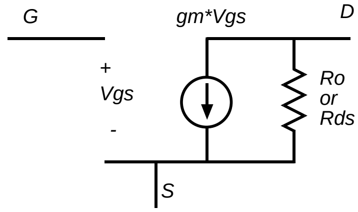
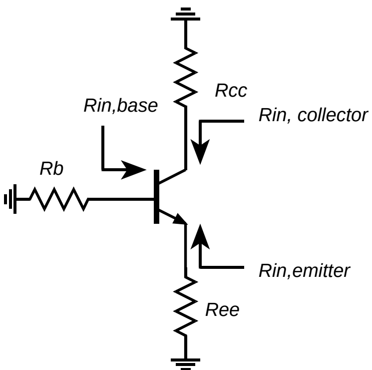
Basics: Amplifiers at Low Frequencies





Left is the equivalent circuit of a bipolar transistor; $g_m = I_E / V_T = 1/r_e$, $V_T = kT/q$, $r_\pi = r_{be} = \beta / g_m$. $R_{ce} = (V_A + V_{CE}) / I_C$. On the right is the FET model. $g_m = v_{sat} c_{ox} W_g$ (short-gate / velocity saturation model) or $g_m = (\mu c_{ox} W_g / L_g)(V_{gs} - V_{th})$ (long-gate / mobility limited model) $R_{ds} = [(1/\lambda) + V_{DS}] / I_D$

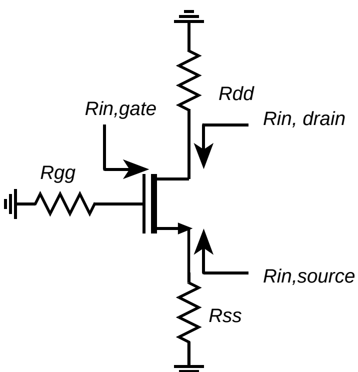


For the bipolar

$$R_{in,base} = (\beta + 1)(r_e + R_{EE})$$

$$R_{in,emitter} = \left(r_e + \frac{R_B}{\beta + 1}\right)\left(\frac{r_{ce} + R_{cc}}{r_{ce}}\right) \approx \left(r_e + \frac{R_B}{\beta + 1}\right)$$

$$R_{in,collector} = r_{ce}\left\{1 + g_m R_{EE} \frac{r_{be}}{r_{be} + R_{EE} + R_B}\right\} \approx r_{ce}\{1 + g_m R_{EE}\}$$



For the fet: THE EQUATIONS ARE THE SAME IF ß is INFINITE!

$$R_{in,gate} = open$$

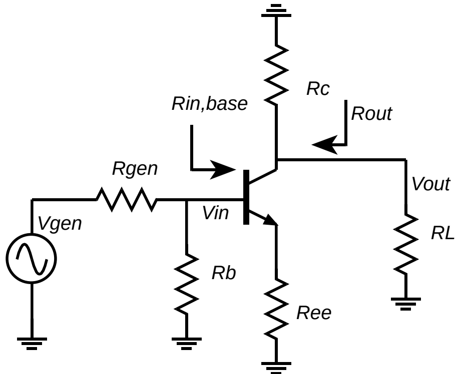
$$R_{in,source} = \left(\frac{1}{g_m}\right)\left(\frac{R_{dd} + R_{ds}}{R_{ds}}\right) \approx \left(\frac{1}{g_m}\right)$$

$$R_{in,drain} = r_{ds}(1 + g_m R_{ss})$$

Be warned that in the equations above Rcc, REE and RB are the equivalent resistances seen by the transistor. So in, the amplifier circuits below, THINK: "what is the effective resistance seen by the transistor?", before plugging into the equations.

Amplifier Stages

Common Emitter and Common Source



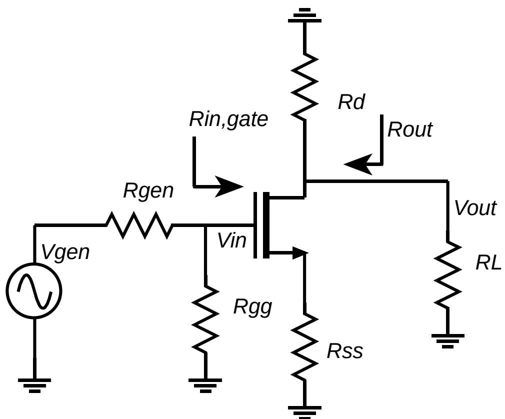
Common emitter:

$$R_{in} = R_B \| R_{in,base} = R_B \| (\beta + 1)(R_{EE} + r_e)$$

$$\frac{V_{in}}{V_{gen}} = \frac{R_{in}}{R_{in} + R_{gen}}$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{-R_{Leq}}{r_e + R_{ee}} = \frac{-(R_c \| R_L \| R_{out,collector})}{r_e + R_{ee}}$$

$$R_{out} = R_c \| R_{out,collector}$$



Common source:

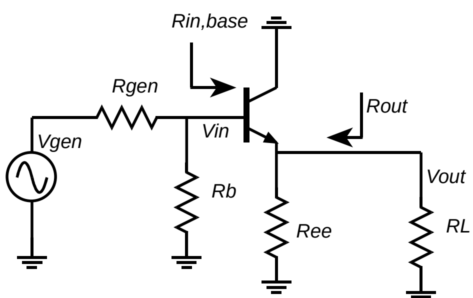
$$R_{in} = R_{gg}$$

$$\frac{V_{in}}{V_{gen}} = \frac{R_{in}}{R_{in} + R_{gen}}$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{-R_{Leq}}{R_{ss} + 1/g_m} = \frac{-(R_d \| R_L \| R_{out,drain})}{R_{ss} + 1/g_m}$$

$$R_{out} = R_d \| R_{out,drain}$$

Common Collector (emitter follower) and common drain (source follower)



for the emitter follower:

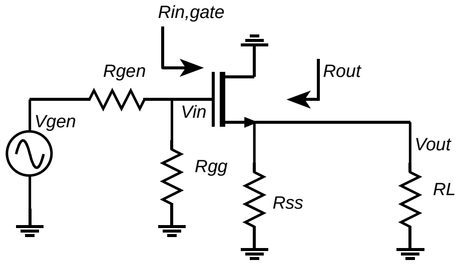
$$R_{in} = R_B \| R_{in,base} = R_B \| (\beta + 1)(R_{EE} \| R_L + r_e)$$

$$\frac{V_{in}}{V_{gen}} = \frac{R_{in}}{R_{in} + R_{gen}}$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{R_{Leq}}{R_{Leq} + r_e} = \frac{R_{ee} \| R_L}{R_{Leq} + r_e}$$

$$R_{out} = R_{ee} \| R_{in,emitter} = R_{ee} \left\| \left(r_e + \frac{R_B}{1 + \beta} \right) \right.$$

Single stage amplifier crib sheet, page 3



For the source follower:

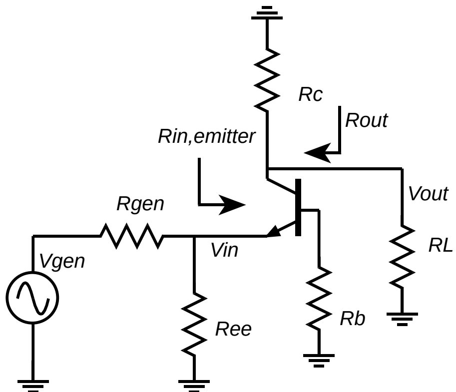
$$R_{in} = R_g$$

$$\frac{V_{in}}{V_{gen}} = \frac{R_{in}}{R_{in} + R_{gen}}$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{R_{Leq}}{R_{Leq} + 1/g_m} = \frac{R_{ss} \| R_L \| R_{ds}}{R_{ss} \| R_L \| R_{ds} + 1/g_m}$$

$$R_{out} = R_{ss} \| R_{in,source} = R_{ss} \| (1/g_m)$$

<u>Common Base and common gate</u>



For the common base:

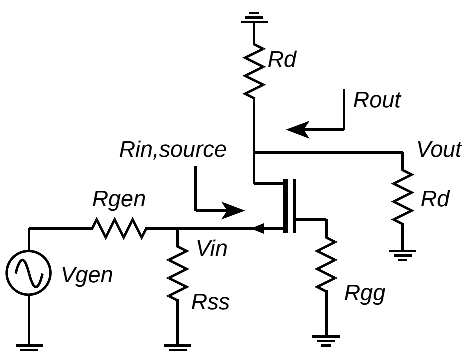
$$R_{in} = R_{EE} \| R_{in,emitter}$$

$$R_{in,emitter} = \left(r_e + \frac{R_B}{\beta + 1} \right) \left(\frac{r_{ce} + R_c \| R_L}{r_{ce}} \right) \approx \left(r_e + \frac{R_B}{\beta + 1} \right)$$

$$\frac{V_{in}}{V_{gen}} = \frac{R_{in}}{R_{in} + R_{gen}}$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{R_{Leq}}{R_{in,emitter}} = \frac{R_C \| R_L}{R_{in,emitter}}$$

$$R_{out} = R_c \| R_{out,collector}$$



For the common gate

$$R_{in} = R_{SS} \| R_{in,source}$$

$$R_{in,source} = \left(\frac{1}{g_m} \right) \left(\frac{r_{ds} + R_d \| R_L}{r_{ds}} \right) \approx \left(\frac{1}{g_m} \right)$$

$$\frac{V_{in}}{V_{gen}} = \frac{R_{in}}{R_{in} + R_{gen}}$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{R_{Leq}}{R_{in,source}} = \frac{R_D \| R_L}{R_{in,source}}$$

$$R_{out} = R_D \| R_{out,drain}$$